

**METHOD FOR EFFICIENT COMPUTATION OF IMAGE
FRAMES FOR DUAL MODULATION DISPLAY SYSTEMS
USING KEY FRAMES**

5 Reference to Related Application

[0001] This application claims the benefit of the filing date of United States patent application No. 60/566,925 filed on 3 May 2004 and entitled "METHOD FOR EFFICIENT COMPUTATION OF
10 IMAGE FRAMES FOR DUAL-MODULATION DISPLAY SYSTEMS
USING KEY FRAMES", which is hereby incorporated by reference.

Technical Field

[0002] The invention relates to processing image frames to be displayed on dual modulation display systems. Certain embodiments of
15 the invention relate to methods and systems for efficient computation of modulation signals.

Background

[0003] In order for images to be displayed on a display, the
20 display generally needs to be connected to an interface configured to receive image data and convert it to signals to be used by the display. The interface varies depending on the type of display. For displays which comprise a modulator, the interface typically comprises a modulator driver coupled to a processor.

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[0004] The processor receives image data and generates a modulation signal for the modulator driver. The modulation signal generally causes the modulator to generate a plurality of pixels in order to reproduce the image. Calculation of the modulation signal can be
30 computationally expensive.

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[0005] The inventor has invented methods and systems which reduce the computational cost of processing image data to be displayed on a dual modulation display system.

5 Summary of Invention

[0006] Video image data comprises a series of frames which change over time to give the viewer the illusion of movement. The inventor has determined that the difference between frames is more often than not less than the dynamic range of the second modulator of a
10 dual modulation system, and that accordingly it may be possible to display a series of frames without adjusting the first modulator. Some aspects of the invention provide methods wherein a first modulation signal and luminance map from one frame (referred to herein as a "key frame") are used for a plurality of other frames, such that the overall
15 computational cost of processing image data is reduced.

[0007] Further aspects of the invention and features of specific embodiments of the invention are described below.

20 Brief Description of Drawings

[0008] In drawings which illustrate non-limiting embodiments of the invention:

Figure 1 shows a dual modulation display system;

Figure 2 shows a method of processing image;

25 Figure 3 shows a method of processing image data according to one embodiment of the invention;

Figure 4 shows a method of processing image data according to another embodiment of the invention; and,

30 Figure 5 shows a method of processing image data according to another embodiment of the invention.

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Description

[0009] Throughout the following description, specific details are set forth in order to provide a more thorough understanding of the invention. However, the invention may be practiced without these
5 particulars. In other instances, well known elements have not been shown or described in detail to avoid unnecessarily obscuring the invention. Accordingly, the specification and drawings are to be regarded in an illustrative, rather than a restrictive, sense.

10 **[0010]** A dual modulation display system, generally indicated by reference character **10** in Figure 1, typically has a rear modulator **12** and a forward modulator **14**. Rear modulator driver **16** is connected to rear modulator **12**, and forward modulator driver **18** is connected to forward modulator **14**. A processor **20** is connected to rear modulator
15 driver **16** and forward modulator driver **18**. Processor **20** receives image data **22** and provides rear and forward modulation signals to rear and forward modulator drivers **16** and **18**, respectively.

[0011] Rear modulator **12** may have a relatively low resolution
20 and forward modulator **14** may have a relatively high resolution. Rear modulator **12** may comprise an array of light emitting diodes (LEDs), a video projector or a backlight. Forward modulator **14** generally comprises a liquid crystal display (LCD).

25 **[0012]** Figure 2 illustrates method **30** carried out by processor **20** of Figure 1. Method **30** begins at block **32**, when processor **20** begins processing a frame of image data **22**. Processor **20** receives the frame's image data **22** at block **34**. At block **36** processor **20** calculates a rear modulation signal for the frame. At block **38** processor **20** calculates an
30 luminance map of light expected to be generated by rear modulator **12** and to be incident on forward modulator **14** when rear modulator **12** is driven by the rear modulation signal for that frame. At block **40**,

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processor **20** divides that frame's image data **22** by the luminance map to generate a forward modulation signal. At block **42**, processor **20** provides the rear and forward modulation signals to rear and forward modulator drivers **16** and **18**, respectively. Method **30** terminates at
5 block **44**, where processor **20** proceeds to process the next frame of image data **22**, beginning again at block **32**.

[0013] When rear and forward modulation signals for a frame are provided to rear and forward modulator drivers **16** and **18**, respectively,
10 rear modulator **12** projects light in accordance with the rear modulation signal onto forward modulator **14** to produce the luminance map. Forward modulator **14** optically modulates the light from rear modulator **12** in accordance with the forward modulation signal to display the image for that frame to a viewer in front of forward
15 modulator **14**.

[0014] In cases where rear modulator **12** comprises a LED array and forward modulator **14** comprises a LCD, processor **20** determines appropriate intensities for each LED of rear modulator **12** for each
20 frame of image data **22** to generate the rear modulation signal for that frame. Processor **20** must then calculate the luminance map of light from rear modulator **12** incident on forward modulator **14** so that processor **20** can generate the forward modulation signal for that frame by dividing the image data **22** by the luminance map. Calculation of the
25 luminance map involves summing the light contributed by each LED to each point on the LCD. The amount of light from a LED reaching a point on the LCD depends on a point spread function for the LED and the power level of the LED. Since these can both be known in principle, one can determine the intensity of light from that LED on
30 each pixel of the LCD.

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[0015] As one skilled in the art will appreciate, calculation of the luminance map at block **38** of Figure 2 is computationally expensive. For example, if forward modulator **14** has a resolution of X by Y, and rear modulator **12** comprises an array of 700 LEDs, the luminance map for each of XY pixels must be calculated based on the point spread functions of all of the 700 LEDs which contribute to illumination of that pixel.

[0016] The invention provides methods and systems for processing image data made up of a series of frames for displaying on a dual modulation display system having first and second modulators. A system according to the invention provides a modulation signal to each of the modulators. The system drives the second modulator with a second modulation signal that takes into account a luminance map of light from the first modulator incident on the second modulator. The first modulation signal and the luminance map are not calculated for every frame. Instead, the first modulation signal and the luminance map are determined only for selected frames referred to as "key frames". The same first modulation signal and corresponding luminance map (collectively referred to as the "key frame parameters") are used to provide the second modulation signal and the luminance map for a one or more other frames.

[0017] The following description makes reference to the example of Figure 1, where the first modulator comprises rear modulator **16** and the second modulator comprises forward modulator **18**. However, it is to be understood that systems according to the invention may be used in association with any type of dual modulation display system wherein the first modulator illuminates the second modulator.

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[0018] Figure 3 illustrates a method **100** according to one embodiment of the invention. Method **100** may be carried out by a processor of a dual modulation display, such as processor **20** of Figure 1. Alternatively, method **100** may be carried out on a processor
5 coupled to an image acquisition device such as a video camera, or an independent processor. Method **100** may be used to process image data in any suitable format, including MPEG, AVI, ASF, WMV, RM, MOV, etc. Method **100** may be used to calculate rear and forward modulation signals for a series of frames. The modulation signals may
10 be provided directly to rear and forward modulator drivers **16** and **18** in real or buffered time, or to electronic storage for future use by rear and forward modulator drivers **16** and **18**.

[0019] Method **100** begins at block **102**, where the processor
15 begins processing a series of frames of image data. At block **104** the processor receives a frame of image data, which is designated as a key frame image. At block **106** the processor calculates a key frame rear modulation signal. At block **108** the processor calculates a key frame luminance map. At block **110** the processor divides the key frame
20 image by the key frame luminance map to generate a key frame forward modulation signal. At block **112** the processor provides the key frame rear and forward driving functions to rear and forward modulator drivers **16** and **18**, or to electronic storage.

25 [0020] At block **114** the processor receives the next frame image of the series of frames. This next frame image is designated as the current frame image. At block **116** the processor divides the current frame image by the key frame luminance map to generate a current frame forward modulation signal. At block **118** the processor selects
30 the key frame rear modulation signal to be the current frame rear modulation signal. At block **120** the processor provides the current

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frame rear and forward driving functions to rear and forward modulator drivers **16** and **18**, or to electronic storage.

[0021] At block **122** the processor determines if **N** frames have
5 been processed since the key frame rear modulation signal and
luminance map were calculated. If not (block **122** NO output), method
100 returns to block **114** where the processor receives the next frame
image, and processes that image as the current frame as described
above. Once **N** frames have been processed (block **122** YES output),
10 method **100** returns to block **104** where the processor receives a new
key frame image and processes it as described above. In situations
where some buffering is possible, the processor may begin the
calculations of blocks **106** and **108** for one or more future key frames in
the background while the current frames of the previous key frame are
15 still being processed.

[0022] The number of frames **N** to be processed using a single key
frame in method **100** may be selected based on expected luminance
changes in the series of frames and/or on the dynamic range of forward
20 modulator **14**. For example, **N** may be selected to be 2, such that every
third frame in the series of frames is designated as a key frame. In
such an example, method **100** would incur approximately one third of
the computation cost associated with processing a series of frames as
compared to method **30** of Figure 2.

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[0023] The rear and forward modulation signals produced by
method **100** result in accurate images displayed on dual modulation
display system **10** for all of the frames in the series of frames, except
for current frames where the luminance differences between the key
30 frame and the associated current frame cannot be accommodated by
forward modulator **14**. For example, a current frame cannot be
accommodated in cases where forward modulator **14** is driven at or

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near either the upper or lower end of its dynamic range for certain pixels of the key frame image, and the current frame image differs from the key frame image for those pixels such that forward modulator **14** would need to be driven at a level outside of its dynamic range in order to accurately represent those pixels of the current frame image.

[0024] In some embodiments, forward modulator **14** comprises an LCD with a dynamic range of 200:1 or greater, such that it can accommodate a wide range of luminance changes between frames. With such a dynamic range and suitable selection of the parameter **N**, luminance changes between a key frame and its associated current frames which cannot be accommodated by the LCD are rare and unlikely to be visible at the rate at which the frames are displayed in typical video applications.

[0025] Figure 4 illustrates a method **200** according to another embodiment of the invention. Method **200** may be carried out in a substantially similar fashion as method **100** of Figure 3. The steps of blocks **202** to **216** of method **200** are substantially the same as those of blocks **102** to **116** of method **100**. Method **200** differs from method **100** in that after the current frame forward modulation signal is generated at block **216**, the processor determines whether the key frame luminance map is suitable for reproducing the current frame image at block **218**.

[0026] The processor may determine whether the key frame should be updated at block **218** based on a comparison of the current frame forward modulation signal generated at block **216** and a range of suitable values for forward modulator driver **16**. Such a comparison may be done on a pixel by pixel basis, with the processor keeping track of the number pixels for which the current frame forward modulation signal is outside the range of suitable values for forward modulator

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driver **16** (referred to herein as “problem pixels”). The processor may also keep track of the locations of the problem pixels. The processor may determine that the key frame should be updated once the number of problem pixels exceeds a predetermined threshold. Alternatively, the processor may determine that the key frame should be updated if the average value by which problem pixels are outside the range of suitable values exceeds a predetermined threshold, a cumulative value by which problem pixels are outside the range of suitable values exceeds a predetermined threshold, or an individual problem pixel is outside the range of suitable values by more than a predetermined threshold.

[0027] If the processor determines that the key frame does not need to be updated (block **218** NO output), method **200** proceeds to block **220**. At block **220** the processor selects the key frame rear modulation signal to be the current frame rear modulation signal. At block **222** the processor provides the current frame rear and forward driving functions to rear and forward modulator drivers **16** and **18**, or to electronic storage. Method **200** then returns to block **214** where the processor receives the next frame image, and processes that image as the current frame as described above.

[0028] If the processor determines that the key frame does need to be updated (block **218** YES output), method **200** proceeds to block **224**. At block **224** the processor updates the key frame rear modulation signal and the key frame luminance map, using the current frame image as the new key frame image. Method **200** then proceeds to block **210** where the processor generates the key frame forward modulation signal, and block **212** where the driving functions are provided to modulator drivers **16** and **18** or to storage, as described above.

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[0029] Depending on the computation capabilities of the processor and the speed at which the series of frames need to be processed, at block **224** the processor may take certain shortcuts in updating the key frame parameters in order to avoid undesirable lag time in the processing of the series of frames. For example, instead of calculating an entirely new key frame rear modulation signal using the current frame image as the key frame image, the processor may update only the portions of the key frame rear modulation signal and key frame luminance map calculated in blocks **206** and **208**, respectively, which correspond to the problem pixels.

[0030] Alternatively, at block **224** the processor may update the key frame rear modulation signal and key frame luminance map calculated in blocks **206** and **208**, respectively, on a section by section basis. For example, the processor could update the key frame parameters corresponding to one quarter of the display area on a first pass through block **224**. The method then proceeds to block **210** and continues as discussed above, with the processor updating the key frame parameters corresponding to the other three quarters on subsequent passes through block **224** until all of the key frame parameters have been updated. If the partial updates of the key frame parameters cause processor to determine at block **218** that the key frame does not need to be updated (block **218** NO output), method **200** may proceed to block **220** without updating all of the key frame parameters.

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[0031] Another way in which the processor may reduce the computation time required at block **224** is to reduce the accuracy requirements for calculation of the updated key frame luminance map. For example, in cases where rear modulator **12** comprises an LED array, the processor may use an approximate Gaussian or other suitable function for each LED's light distribution, rather than the actual point spread function for each LED. Such an approximation reduces the

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computational cost of updating the key frame parameters, and any imperfections introduced thereby are unlikely to be visible to a viewer watching display **10**. Furthermore, the approximation may be used only for an interim period while the processor calculates the new key frame luminance map using the actual point spread functions in the background. The approximation may be improved in successive frames using the actual calculations until the new key frame luminance map has been completely calculated.

10 **[0032]** Figure 5 illustrates a method **300** according to another embodiment of the invention. Method **300** may be carried out in a substantially similar fashion as methods **100** and **200** of Figures 3 and 4 respectively. The steps of blocks **302** to **322** of method **300** are substantially the same as those of blocks **202** to **222** of method **200**.

15 Method **300** differs from method **200** in that when the processor determines that the key frame does need to be updated (block **318** YES output), method **300** proceeds to block **324** where the processor selects a standard key frame and uses the parameters from the standard key frame to generate the key frame forward modulation signal in block

20 **310**. Processor may also update the key frame parameters using the current frame image as the key frame image in the background at block **326** while the standard key frame parameters are being used to process interim frames, as indicated by the dotted lines in Figure 5.

25 **[0033]** The standard key frame selected at block **324** may comprise a key frame for which the key frame parameters are already calculated. Examples of standard key frames include frames where rear modulator **12** is driven:

- at a constant percentage (e.g. one half) of the full intensity across the whole display area;
- at full intensity across the whole display area;

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- at a constant percentage (e.g. one half) of the full intensity across a selected portion of the display area; and,
- at full intensity across a selected portion of the display area.

Alternatively, the processor may store previously processed key frames, and any key frame for which the key frame parameters have already been calculated may be selected as the standard key frame at block **324**.

[0034] Certain elements of methods **100**, **200** and **300** described above may be combined with each other to produce other methods according to various embodiments of the invention. For example, in method **100** the processor may determine if the key frame should be updated between blocks **116** and **118**, as in block **218** of method **200**.

[0035] Consider for example a method wherein every eighth frame is designated as a key frame ($N=7$), and the processor determines if the key frame should be updated after each current frame forward modulation signal is generated. In any such method wherein certain frames are designated as key frames, the processor may “work ahead” by buffering a number of frames and processing one or more future key frames in the background while the active key frame parameters are being used to process the current frames for the active key frame. To update the key frame, the processor may take the shortcuts discussed above with respect to block **224** of Figure 4, or may select standard key frame parameters as discussed above with respect to block **324** of Figure 5.

[0036] Additionally or alternatively, when the processor determines that the key frame needs to be updated for one of the 7 current frames being processed, the processor can determine if one of the future key frames would be suitable for processing the current frame. The processor may determine if a future key frame is suitable by dividing the current frame image by the future key frame luminance

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map. As one skilled in the art will appreciate, the division is a linear process of one operation per pixel and is relatively fast when compared to calculating a plurality of point spread functions for each pixel.

Accordingly, a saving in computational cost may be achieved even if a plurality of future and past key frames are checked to determine their suitability for processing the current frame. In practice, it is generally only desirable to check a few key frames ahead of and/or behind the current frame, as such key frames are the most likely to be suitable matches to the image data of the current frame.

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[0037] Certain implementations of the invention comprise computer processors which execute software instructions which cause the processors to perform a method of the invention. For example, one or more processors in a dual modulation display system may implement data processing steps in the methods described herein by executing software instructions retrieved from a program memory accessible to the processors. The invention may also be provided in the form of a program product. The program product may comprise any medium which carries a set of computer-readable signals comprising instructions which, when executed by a data processor, cause the data processor to execute a method of the invention. Program products according to the invention may be in any of a wide variety of forms. The program product may comprise, for example, physical media such as magnetic data storage media including floppy diskettes, hard disk drives, optical data storage media including CD ROMs, DVDs, electronic data storage media including ROMs, flash RAM, or the like or transmission-type media such as digital or analog communication links. The instructions may be present on the program product in encrypted and/or compressed formats.

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[0038] Where a component (e.g. a software module, processor, assembly, device, circuit, etc.) is referred to above, unless otherwise indicated, reference to that component (including a reference to a “means”) should be interpreted as including as equivalents of that component any component which performs the function of the described component (i.e., that is functionally equivalent), including components which are not structurally equivalent to the disclosed structure which performs the function in the illustrated exemplary embodiments of the invention.

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[0039] As will be apparent to those skilled in the art in the light of the foregoing disclosure, many alterations and modifications are possible in the practice of this invention without departing from the spirit or scope thereof. For example, the processor could be integrated with the first and second modulator drivers. Also, in embodiments of the invention for RGB implementations, the luminance map may comprise a color intensity map. Accordingly, the scope of the invention is to be construed in accordance with the substance defined by the following claims.

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